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J.C. KEITH T.S., ST. MARYS T.S.
AND E.V. BUCHANAN T.S.

INVESTIGATION OF CONCRETE DETERIORATION

Report No 88-164-K

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ABSTRACT

An investigation into the deterioration of concrete tower pads at three western Ontario transformer stations (T.S.) concludes that the lack of air-entrainment in the concrete is the cause of the deterioration.

job	file	date	report no.
42-151-570	842.5 STAS W	August 10, 1988	88-164-K

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	PROCEDURES	1
3.0	OBSERVATION AND DISCUSSION	1
3.1	J.C. Keith T.S.	1
3.2	St. Marys T.S.	2
3.3	E.V. Buchanan T.S.	2
4.0	CONCLUSIONS AND RECOMMENDATIONS	3
TABLE 1		4
FIGURES 1 to 11		6
APPENDIX A		A1
APPENDIX B		B1
DISTRIBUTION		last page

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To: Mr. J.V. Doyle
Civil Works Department
Thermal & Hydraulic Generation Division

Attn.: Messrs.K.F. Chiu/D. Grant

J.C. KEITH T.S., ST. MARYS T.S. AND E.V. BUCHANAN T.S.
INVESTIGATION OF CONCRETE DETERIORATION

1.0 INTRODUCTION

In accordance with instructions received from Mr. D. Grant of the Civil Works Department, an investigation was carried out in May 1988 at J.C. Keith T.S., St. Marys T.S. and E.V. Buchanan T.S. to determine the cause and extent of localized concrete deterioration in tower footings, tank supports, and transformer support walls.

This report contains the results of the investigation and identifies the probable cause of the deterioration.

2.0 PROCEDURES

The investigation consisted of visual examination, selective coring with a 100 mm nominal diameter water-cooled diamond drill and laboratory testing of the concrete cores. A summary of the cores is given in Table 1.

A limited trial was conducted (J.C. Keith T.S.) using non-destructive ultrasonic pulse velocity measurements to determine the feasibility of this technique for evaluating the in situ quality of the concrete.

3.0 OBSERVATION AND DISCUSSION

3.1 J.C. Keith T.S.

A visual examination of a few concrete tower pads indicates that some pads are in good to excellent condition, while similar pads in the same tower have completely disintegrated. The number and location of damaged pads will be reported separately by Civil Works.

In order to determine the cause and extent of the deterioration, a total of eight cores were drilled from the tower footings.

Figures 1 to 5 show the drilling of cores from J.C. Keith T.S.

The cores, as received in the laboratory, are shown in Figure 6. The coring, in most cases, was discontinued within 200 mm of the surface since there was no evidence of deterioration below this depth.

Visual and microscopic examination of the cores indicates that the concrete has failed due to cycles of freezing and thawing (Appendix A). This concrete is not air-entrained and as such is not resistant to the type of exposure to which it has been subjected.

Ultrasonic pulse velocity measurements confirm that this deterioration is progressive. Concrete in pads that is visually sound exhibits good pulse velocities. That which is questionable exhibits lower velocities, and the one in obvious disrepair has the lowest velocities. The measurements are given in Appendix B.

3.2 St. Marys T.S.

The saddles for the two oil storage tanks at this station were visually examined. All saddles displayed extensive cracking in the area immediately below the tanks and less severe cracking closer to the ground.

Two cores were drilled through the north saddle of the west tank. (Figures 7 and 8). A summary of the cores is given in Table 1.

The core drilled immediately below the tank (Core 1) displayed extensive cracking throughout. No physical tests were done on this sample; however, if tested in compression, it would probably fail at a very low load. Likewise, the concrete core near the ground level (Core 2) was not tested; however, this core is visually sound and should have adequate compressive strength.

Although the compressive strengths may be high, this concrete is not air-entrained and therefore not durable where exposed to cycles of freezing and thawing.

The extent of deterioration of the saddle can only be determined after the removal of the deteriorated concrete.

3.3 E.V. Buchanan T.S.

Visual inspection of the tower pads and tank support saddles at E.V. Buchanan T.S. indicates similar deterioration to that noticed at J.C. Keith T.S. and St. Marys T.S. No cores were drilled from the pads or saddles at E.V. Buchanan T.S.

A third area of concern at this station is the transformer support walls (Figure 9). Repairs had previously been made to these walls and they now exhibit further deterioration.

To assess the extent of the damage, two cores were drilled from the wall, Core 1 at the interface of the new and old concretes and Core 2 in the new concrete (Figure 10 and 11).

Examination of Core 1 indicates that not all of the old deteriorated concrete had been removed during the repair and as a result further deterioration of the original concrete has caused reflection cracks in the repairs.

In Core 2, three different types of concrete were noted. The inside end of the core contains the original concrete, and progressing to the outer surface, there are two layers of repair material. Improper repair procedure is the cause for the subsequent deterioration of this repair.

4.0 CONCLUSIONS & RECOMMENDATIONS

The deterioration noted at the three stations is typical of concrete that is non-air-entrained and has been subjected to cycles of freezing and thawing. The deterioration is progressive and extends from the most to the least exposed area. It is therefore expected that the outer skin of concrete will show severe deterioration, while the interior will be relatively unaffected.

Since the concrete is non-air-entrained, it will never be durable. The fact that some footings are completely deteriorated while others are apparently sound is attributed to the degree of exposure that they have been subjected to.

In the case of the deteriorated pads and saddles, the most economical solution is to remove all deteriorated concrete and replace it with an air-entrained concrete that is compatible with the original concrete. It should be noted that it is important to remove all deteriorated material.

Ultrasonic pulse velocity measurements were effective in determining the extent of deterioration. An ultrasonic survey combined with a visual inspection may provide a basis for deciding which pads should be repaired.

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Table 1
J.C. Keith T.S., St. Marys T.S. and E.V. Buchanan T.S.
Concrete Core Summary

Station	Core Number	Location	Remarks
J. C. Keith. T.S.	1	Blue phase of 23J4CPT	Extensive cracking on the surface (Figure 1). Ultrasonic pulse velocity = 1640 m/sec.
	2	White phase of 23J4CPT	Same age and service condition as Core 1, but with no visible signs of distress (Figure 2). Ultrasonic pulse velocity = 4700 m/sec.
	3	Blue phase of 23J4CPT	Drilled at same location as Core 1, except that the core was drilled horizontally into the side of the footing.
	4	Northeast leg of tower 23T2-T	Only top portion of the core recovered. Deterioration does not extend beyond top 150 mm
	5	Unused footing in southwest portion of yard	Refer to Figure 3.
	6	Unused footing immediately north of Core 5 footing	Core drilled to reinforcing steel (Figure 4).
	7	Unused footing immediately north of Core 5 footing	Core drilled to 400 mm (Figure 4).
	8	Unused footing north-east of Core 5 footing	Refer to Figure 5.

Table 1 (cont'd)

J.C. Keith T.S., St. Marys T.S. and E.V. Buchanan T.S.
Concrete Core Summary

Station	Core Number	Location	Remarks
St. Marys T.S.	1	Drilled through saddle of west tank, close to tank	See Figures 7 and 8.
	2	Drilled through north saddle of west tank, close to ground	See Figures 7 and 8.
E.V. Buchanan T.S.	1	Drilled through interface of old and new concrete in transformer support wall	See Figure 10.
	2	Drilled through new concrete in transformer support wall	See Figure 10.

FIGURE 1 - Blue phase of 23J4CPT. Note extensive cracking of concrete.

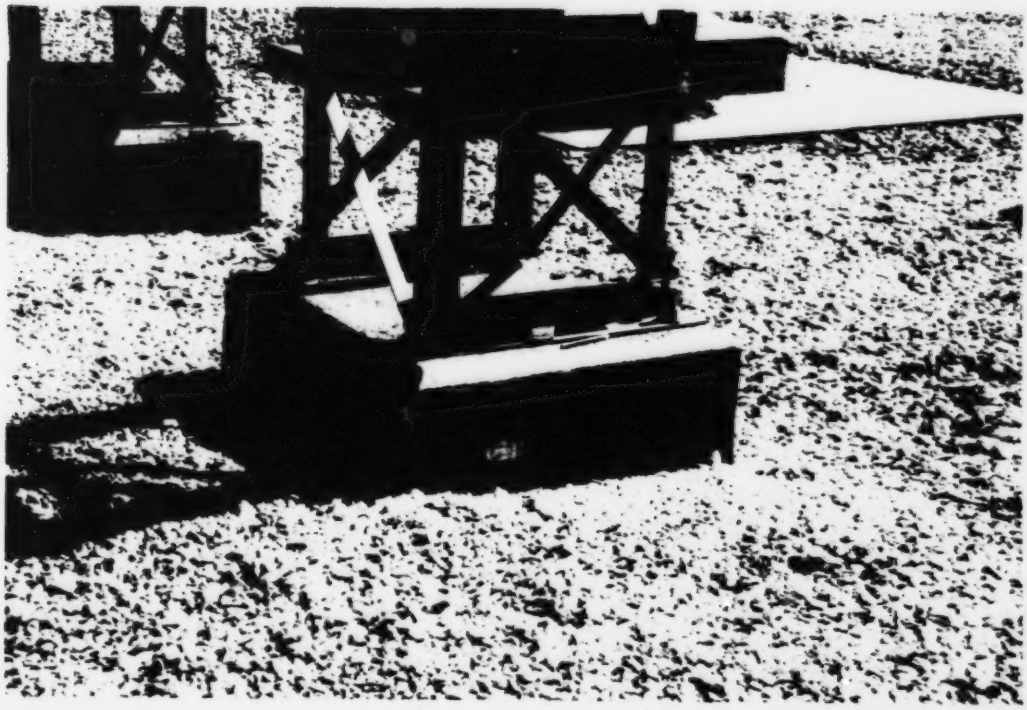

FIGURE 2 - White phase of 23J4CPT. Note the absence of cracking in this pad.

FIGURE 3 - Core 5 drilled on an unused footing in the southwest corner of the yard. Note depth of deterioration.

FIGURE 4 - Cores 6 and 7. Core 6 drilled to reinforcing bar depth. Core 7 drilled to 400 mm.

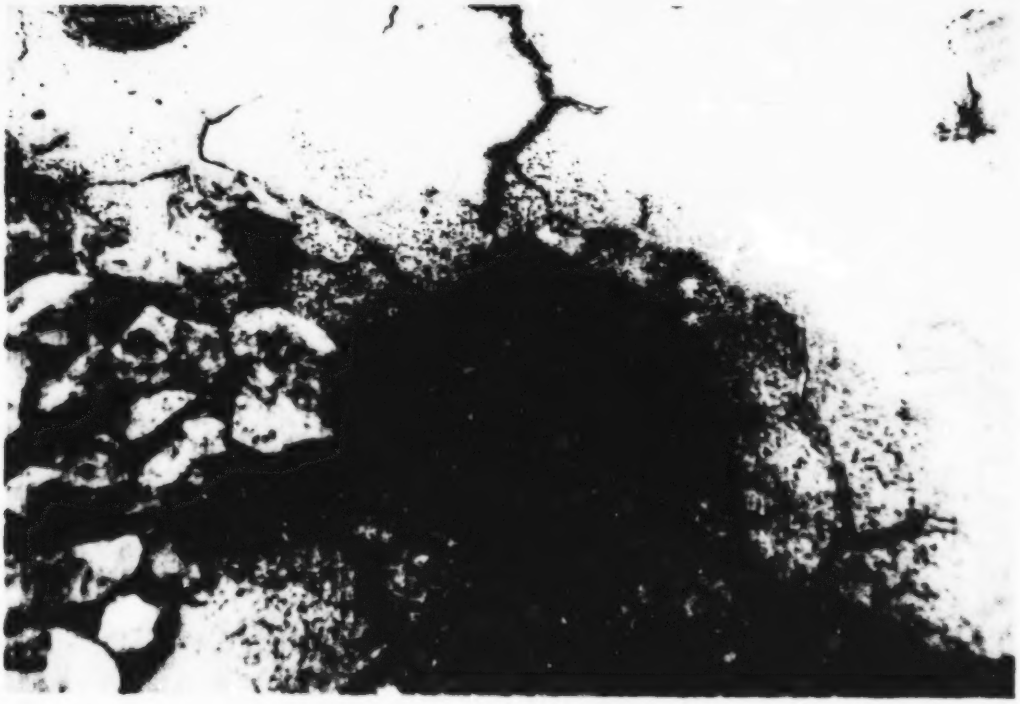

FIGURE 5 - Core 8. Note depth of deterioration in core hole.

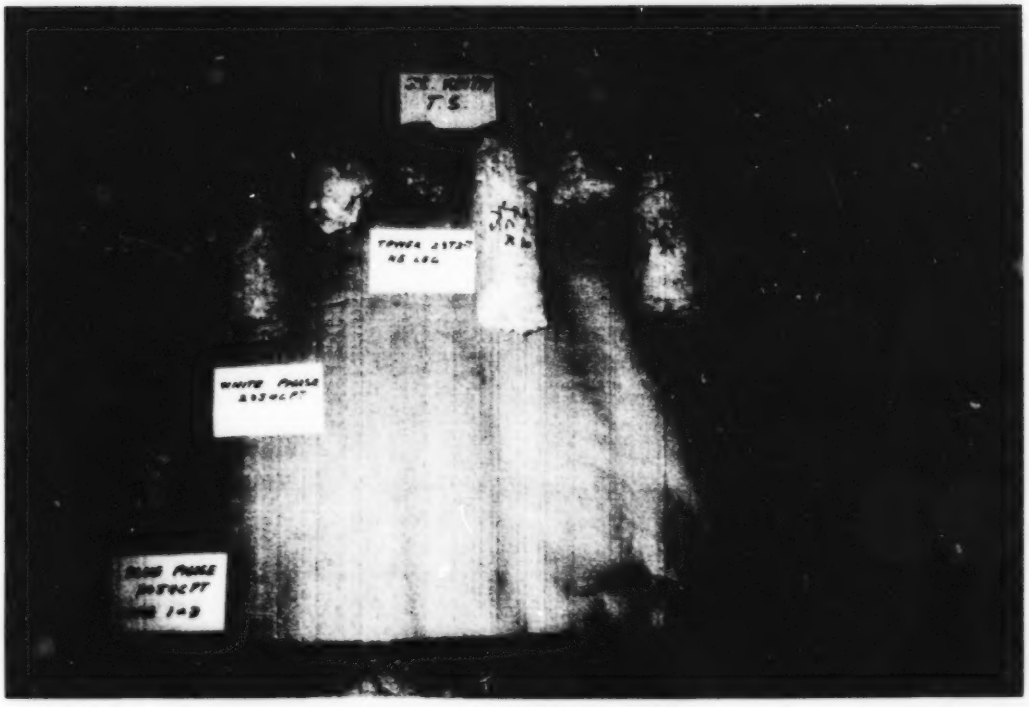

FIGURE 6 - Overall view of cores drilled from J.C. Keith T.S.

FIGURE 7 - Drilling cores from the tank saddle at St. Marys T.S.

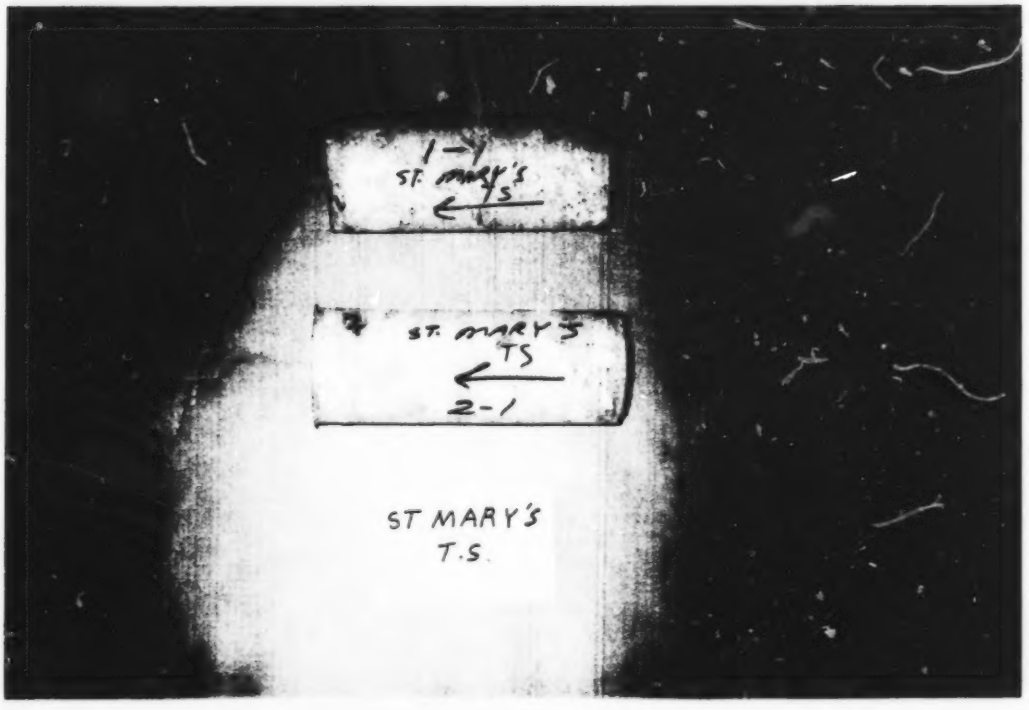

FIGURE 8 - Photo of cores drilled from saddle shown in Figure 7. Core 1 drilled near the tank and Core 2 drilled near the ground. Note extensive cracking of Core 1, while Core 2 is sound.

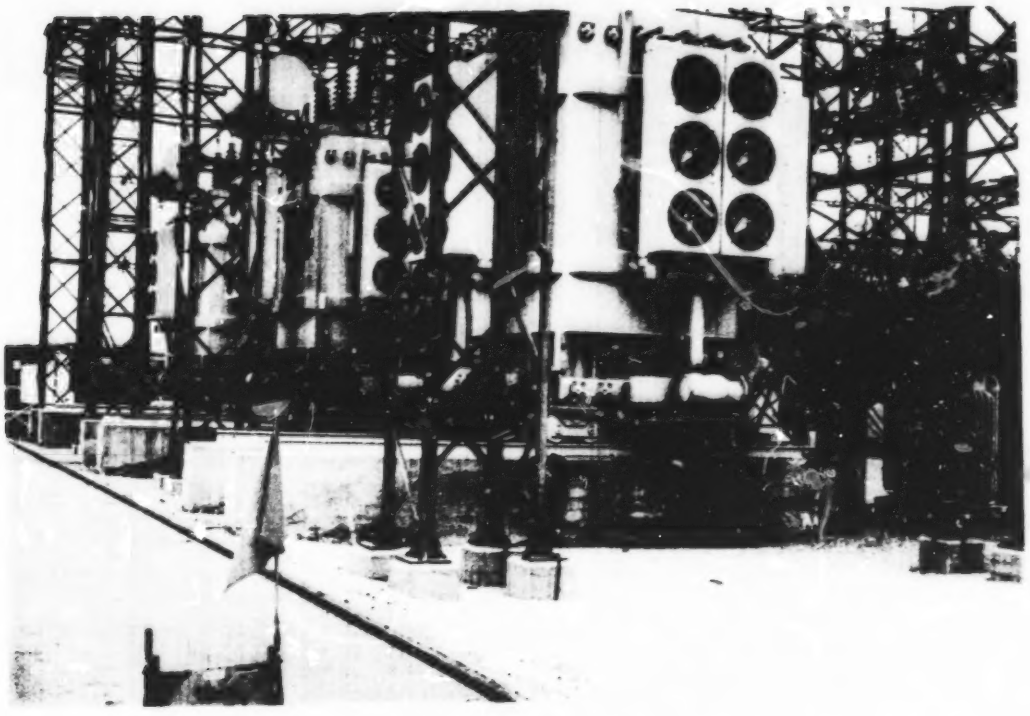

FIGURE 9 - Transformer support walls. Note white efflorescence at right corner of foreground and repaired area on left (behind flag).

FIGURE 10 - Core 1 drilled at interface of repair and original concrete and Core 2 drilled in repair concrete.

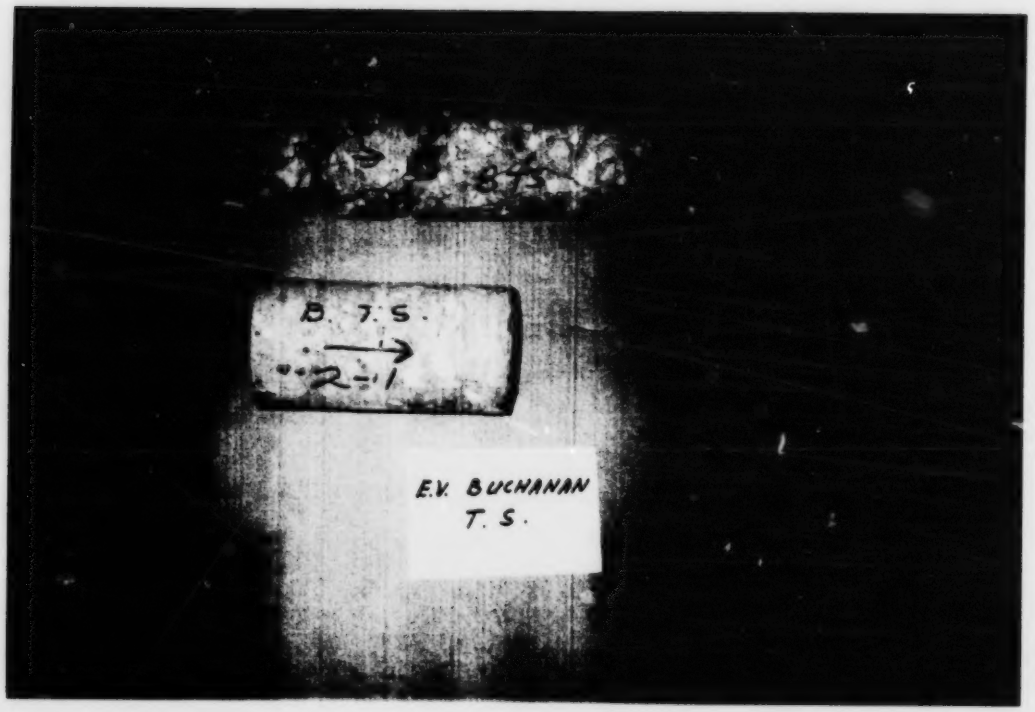

FIGURE 11 - Photo of cores obtained from transformer support wall. Core 1 drilled at interface. Note old concrete below first crack (approximately 50 mm). Core 2 shows three different concretes.

APPENDIX A

J.C. Keith T.S.

Microscopic Examination of Core Samples

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MEMORANDUM

MR. H. CARATIN
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July 12, 1988

842.15(T)

J.C. Keith TS, E.V. Buchanan TS and St. Mary's TS
Preliminary Examination of Deteriorated Concrete

This memo summarizes a preliminary microscopic examination of thin sections prepared from concrete cores drilled at J.C. Keith TS, E.V. Buchanan TS and St. Mary's TS. A detailed analysis including photomicrographs will be issued at a later date.

J.C. Keith

Core 1 - 1
- thin section prepared from section approximately 150 mm below the top surface
- non air-entrained paste
- extensive Alkali Aggregate Reaction (AAR)
  . gel development
  . ettringite and gel at periphery of silicate grains
- alteration of sparite and siliceous sparite grains

E.V. Buchanan TS

Core 2 - 1
- thin section prepared from a section approximately 200 mm below the top surface
- non air-entrained paste
- large number of unhydrated cement grains
- high proportion of these grains are surrounded by gel
- minor AAR
  . fine grained, fossiliferous limestones exhibit extensive cracking which tend to be lined with amorphous gel
- paste extensively cracked
- cracks are carbonated

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St. Mary's TS

Core 1 - 1
- thin section prepared from a section approximately 250 mm below the top surface
- non air-entrained paste
- large number of unhydrated cement grains
- minor AAR
- extensive cracking concentrated in and around fine grained siliceous dolomite and micritic dolomite
- minor carbonation along some cracks

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APPENDIX B

J.C. Keith T.S.
Ultrasonic Pulse Velocity Measurements

J.C. Keith T.S.

Ultrasonic Pulse Velocity Measurements

Ultrasonic pulse velocity measurements using a PUNDIT were taken at selected concrete tower footings. In addition to the measurements, the condition of the concrete was assessed visually as follows:

Good	-	Visually sound with no cracking or spalling.
Questionable	-	A small amount of cracking with no spalling.
Poor	-	Extensive cracking with small amount of spalling.
Very Poor	-	Extensive crack and spalling.

As a guide to the assessment of the condition of the concrete using ultrasonic pulse velocity the following criteria may be used:

	Velocity (m/sec)
Good -	> 3700
Questionable -	3000 - 3700
Poor -	< 3000

Table B1 gives a summary of the measurements.

TABLE B1

J.C. KEITH T.S.

ULTRASONIC PULSE VELOCITY MEASUREMENTS

LOCATION	VISUAL ASSESSMENT	LOCATION	READING SEC	PATH LENGTH m	PULSE VELOCITY m/SEC	PULSE VELOCITY FT/SEC
Tower Pad 23J4CPT (white)	Good	1	221	1.020	4620	15100
		2	217	1.020	4700	15400
		3	216	1.020	4720	15500
		4	215	1.020	4740	15600
		5	217	1.020	4700	15400
		6	217	1.020	4700	15400
		7	216	1.020	4720	15500
		8	216	1.020	4720	15500
Tower Pad -Green Beside 23J4CPT (blue)	Poor	1	615	1.027	1670	5500
		2	645	1.027	1590	5200
		3	595	1.028	1730	5700
		4	656	1.028	1570	5100
		5	660	1.029	1560	5100
		6	741	1.029	1390	4600
		7	495	1.030	2080	6800
		8	685	1.030	1500	4900
Tower T2L4-L						
Pad 1	Good	1	98	0.462	4710	15500
		2	97	0.462	4760	15600
		3	100	0.462	4620	15200
Pad 2	Good	1	99	0.453	4580	15000
		2	99	0.455	4600	15100
		3	99	0.457	4620	15100
Pad 3	Poor	1	159	0.453	2850	9300
		2	171	0.455	2660	8700
		3	171	0.457	2670	8800
Pad 4	Poor	1	180	0.457	2540	8300
		2	167	0.455	2720	8900
		3	170	0.453	2660	8700
Tower 23T3T11-3						
	Good	1	100	0.458	4580	15000
		2	99	0.458	4630	15200
		3	98	0.458	4670	15300
	Questionable (cracking)	1	114	0.462	4050	13300
		2	114	0.462	4050	13300
		3	107	0.462	4320	14200
	Poor	1	185	0.466	2520	8300
		2	195	0.466	2390	7800
		3	361	0.466	1290	4200
	Good	1	95	0.455	4790	15700
		2	96	0.455	4740	15500
		3	97	0.455	4670	15400

TABLE B1 (CONT'D)

J.C. KEITH T.S.

ULTRASONIC PULSE VELOCITY MEASUREMENTS

LOCATION	VISUAL ASSESSMENT	LOCATION	READING SEC	PATH LENGTH m	PULSE VELOCITY m/SEC	PULSE VELOCITY FT/SEC
Tower L3P-L						
Pad 1	Good	1	101	0.458	4530	14900
		2	101	0.458	4530	14900
		3	101	0.458	4530	14900
Pad 2	Good	1	98	0.450	4590	15100
		2	100	0.452	4520	14800
		3	100	0.454	4540	14900
Pad 3	Questionable	1	136	0.453	3330	10900
		2	144	0.454	3150	10300
		3	151	0.454	3010	9900
Pad 4	Questionable	1	171	0.458	2680	8800
		2	181	0.458	2530	8300
		3	187	0.458	2450	8000
Tower 23T1-T						
Pad 1	Good	1	115	0.461	4010	13200
		2	105	0.461	4390	14400
		3	103	0.461	4480	14700
Pad 2	Questionable	1	120	0.461	3840	12600
		2	116	0.460	3970	13000
		3	103	0.459	4460	14600
Pad 3	Questionable	1	97	0.457	4710	15500
		2	96	0.458	4770	15700
		3	96	0.459	4780	15700
Pad 4	Good	1	100	0.457	4570	15000
		2	97	0.458	4720	15500
		3	99	0.459	4640	15200
Tower 23T2-T						
Pad 1	Questionable	1	121	0.461	3810	12500
		2	110	0.461	4190	13700
		3	113	0.461	4080	13400
Pad 2 (crack)	Poor	1	155	0.460	2970	9700
		2	377	0.460	1220	4000
		3	140	0.460	3290	10800
Pad 3 (crack)	Poor	1	96	0.460	4790	15700
		2	102	0.460	4510	14800
		3	134	0.460	3430	11300
Pad 4	Poor	1	104	0.460	4420	14500
		2	101	0.460	4550	14900
		3	120	0.460	3830	12600